

Vegetation Impacts Upon Stream Width



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Complexity	Value as a Design Tool	Cost
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OVERVIEW

Riparian vegetation has a significant influence upon the regime width of alluvial channels. Aside from numerous ecological functions, the riparian vegetation canopy reduces near-bank velocity and intercepts rainfall, while the roots bind and strengthen the soil. Consequently, well-vegetated streams maintain a stable width that is 20-50 percent narrower than comparable streams lacking vegetation. Existing regime relations for channel width seldom take into account the influence of vegetation.

This technical note presents generalized width predictors for sand-bed and gravel-bed rivers with various riparian vegetation characteristics along the banks. These width predictors have been developed for use in situations where data to develop specific hydraulic geometry relationships are lacking. The predictors are useful as regime relations, or to augment analytical computations when determining a stable channel width for restoration projects.

The width predictors for sand-bed rivers were developed from data collected at 58 meandering sand-bed rivers in the United States (Soar and Thorne 2001) and include confidence limits. The width predictors for gravel-bed rivers were developed from published gravel-bed stream data and also include confidence limits.

INTRODUCTION

Hydraulic geometry relationships are often used in the hydraulic design of channels for stream restoration projects. Hydraulic geometry theory is based on the concept that a river system tends to develop in a predictable way, producing an approximate equilibrium between the channel and the inflowing water and sediment (Leopold and Maddock 1953). The theory typically relates a dependent variable, such as width or slope, to an independent or driving variable, such as discharge or drainage area. Hydraulic geometry relationships are developed from field observations at stable and alluvial cross-section for a specific river, watershed, or for streams with similar physiographic characteristics. However, the relationships are empirical, and extrapolation to watersheds, or to times different from those represented by the data used to develop a given relationship, is risky. As design tools, hydraulic geometry relationships may be useful for preliminary or trial selection of channel width.

When a hydraulic geometry relationship is to be used for a channel restoration design it is best to use one developed from stable alluvial reaches of the project stream. It is required that the stable reaches used to develop the relationship have similar physiographic conditions. If there are no stable reaches or if the range of discharges is insufficient, other streams or tributaries in the same watershed

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may be used to develop the hydraulic geometry relationship. The third choice is to use regional relationships. In all cases it is imperative that data used to develop hydraulic geometry relationships be from stable reaches and that the watersheds and channel boundary conditions should be similar to those in the project channel.

Unfortunately, most stream restoration projects are in watersheds that lack sufficient data to develop site-specific hydraulic geometry relationships. Therefore, generalized width predictors have been developed herein. These predictors include confidence limits and may be used for general guidance when other more specific guidance is unavailable.

SAND-BED RIVERS

The hydraulic geometry width predictors for sand-bed rivers were developed for various stream types with different bank characteristics (Figure 1). They have been generalized and include confidence limits. They were developed from data on 58 meandering sand-bed rivers in the United States, which is part of the Brice data collection (Soar and Thorne 2001).

The Brice data collection is a database of approximately 350 American alluvial streams originally developed by J. C. Brice of the United States Geological Survey (USGS) during the 1970s and 1980s. The database was analyzed and the information contained in the database catalogued as part of research at Johns Hopkins University (JHU) sponsored by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL).

Further research at the University of Nottingham, UK, again sponsored by CHL, expanded the parameters included in the database through both analysis and further fieldwork. The database, which now resides at CHL, currently includes a tabulated inventory of measured and calculated channel

parameters together with archived maps, time-sequential aerial photographs, cross-section measurements, bank vegetation descriptions and photos, and bed and bank material gradations. Data for some streams is incomplete.

About 58 of the Brice sites have the full complement of data. These were used to develop the following hydraulic geometry width predictors. Sufficient data were collected on the 58 streams to determine both bankfull discharge and effective discharge. Data were collected from stable reaches, so bankfull discharge should be the most reliable approximation for the channel-forming discharge. In many of these meandering sand-bed rivers, the effective discharge was significantly less than the bank-full discharge.

TREE COVER

For design purposes, the bank-full discharge was used to define the width predictor. The data were divided into two sets: type T1, in which there was less than 50 percent tree cover on the banks (Figure 2); and type T2, in which tree cover on the banks was 50 percent or greater (Figure 3). All sites were tree-lined to some degree, so the predictors should not be used for grass-lined or thinly vegetated banks. The percentage of silt and clay in the banks was found to be insignificant for these rivers, possibly because the root-binding properties of the trees were more significant in stabilizing the bank than cohesive forces. "Hydraulic Design of Stream Restoration Channels" (Copeland et al. 2001) describes in more detail both the Brice data set and the research that resulted in the development of these width predictors.

The hydraulic geometry width predictor is expressed by the general equation

$$W = aQ^b$$

where W is the channel top width, Q is the channel-forming discharge, and values for the coefficient 'a' and the exponent 'b' are given

in Table 1. The hydraulic geometry width predictors each include two sets of confidence bands. The 95-percent mean response limit provides the band in which one can be 95-percent confident that the mean value of the width will occur. This is the confidence interval for the regression line. This provides the range of average values of width that can be expected for a given discharge. The 90-percent single response limit provides the envelope curves that contain 90 percent of the data points. This is the confidence interval for an individual predicted value. This provides the engineer with the range of possible widths that have been observed to correspond to a given discharge. The confidence interval on an individual predicted value is wider than the confidence interval of the regression line since it includes both the variance of the regression line plus the squared standard deviation of the data set. While the equations given in Table 1 may be used for preliminary design purposes, they are subject to several limitations. In the absence of stage-discharge relationships at each site, the equations are based on flow resistance considerations. As cross-sectional geometry was used to calculate discharge, discharge is not truly independent of width in this analysis. Furthermore, only one cross section was

measured at each site, and identification of the bankfull reference level, although based on field experience and geomorphic criteria, is always subject to a degree of uncertainty. These factors contribute to the observed variability in the width relationships. Finally, small rivers are not well represented in the data set, and these curves should not be applied when discharge is less than $17 \text{ m}^3\text{s}^{-1}$ in type T1 channels and less than $38 \text{ m}^3\text{s}^{-1}$ in type T2 channels.

GRAVEL-BED RIVERS

A review of the published gravel-bed stream data and hydraulic geometry width predictors for North American and British streams (Soar and Thorne 2001) revealed that North American gravel-bed rivers are generally wider than those found in the United Kingdom (U.K.), assuming discharge and other conditions are equal. North American data used to develop the hydraulic geometry relationship included data from Brandywine Creek in Pennsylvania (Wolman 1955); Alaskan streams (Emmett 1972); Upper Salmon River in Idaho (Emmett 1975); Colorado, New Mexico, Oregon, Pennsylvania, Tennessee, Utah, West Virginia and Wyoming (Williams 1978);

Table 1. Hydraulic geometry width predictors for sand-bed channels, S.I. units m and m^3/sec (English units ft and ft^3/sec). $W = a Q^b$

Data source	Sample size	A	90% single response limit for a	95% mean response limit for a	b	R ²
All sand-bed streams	58	4.24 (2.34)	2.34-7.68 (1.29-4.24)	3.90-4.60 (2.15-2.54)	0.5	0.76
Type T1: <50% tree cover	32	5.19 (2.86)	3.30-8.14 (1.82-4.49)	4.78-5.63 (2.64-3.11)	0.5	0.87
Type T2: >50% tree cover	26	3.31 (1.83)	2.15-5.08 (1.19-2.80)	3.04-3.60 (1.68-1.99)	0.5	0.85

Note R² refers to linear regression equations (not given) where b was variable. Exponent b was found not to be statistically different from 0.5, which was chosen for convenience.

Ontario, Canada (Annable 1996); and the Rocky Mountain region of Colorado (Andrews 1984). United Kingdom data included data from Nixon (1959), Charlton et al. (1978), and Hey and Thorne (1986). The hydraulic geometry relationships are shown in Figure 4. The difference in these regression curves cannot be satisfactorily explained using the site descriptions given in original publications. A possible explanation is that the U.K. sites have, on the average, more resistant banks than the North American sites. Another plausible explanation is that width in mobile-gravel bed streams varies with flow variability and the North American sites on the average may be more flashy. Still another possibility is that the North American sites may be more active, that is, they have a higher concentration of sediment transport. Further research is required to validate these hypotheses.

The hydraulic geometry width predictors for United Kingdom and North American gravel bed streams are presented with confidence bands in Figures 5 and 6, respectively. Exponents and coefficients for the hydraulic geometry equation are given in Table 2. The gravel bed river data comprise a wide range of bank material types (e.g., cohesive, sand, gravel and composite banks of various strata). However, different width-discharge relationships based on different types of material or bank vegetation could not be derived for the North American river data due to limitations in available information. Sufficient data were available from the U.K. gravel-bed rivers to develop distinct width predictors based on “erodible” banks (low density of trees) and “resistant” banks (high density of trees). These are presented in

Figures 7 and 8. These hydraulic geometry relations may be used for preliminary design purposes, recognizing that considerable variability may occur for areas different from the streams used in the development of the equations.

CONCLUSIONS

Hydraulic geometry relationships can be useful design tools in the early stages of the hydraulic design of stream restoration projects. However, since the relationships are empirical they are most often site-specific. The generalized width predictors presented herein are for sand-bed and gravel-bed alluvial rivers with distinctions made by general bank vegetation. These width predictors were developed, with confidence limits, for use on projects that lack sufficient data to develop site-specific hydraulic geometry relationships. The sand-bed width predictors, developed from data in the Brice data set currently housed at CHL, are divided into two sets by tree cover. The gravel-bed width predictors were developed from published data on North American and British streams. Only the data from the British streams are segregated by tree cover, providing separate curves for banks with a low density of trees and banks with a high density of trees. A more complete discussion of both the Brice data set and the development of these width predictors is presented in “Hydraulic Design of Stream Restoration Projects” (Copeland et al. 2001). That document also presents a methodology covering every step in the hydraulic design of stream restoration projects.

Table 2. Hydraulic geometry width predictors for gravel-bed channels, S.I. units m and m³/sec (English units ft and ft³/sec); $W = a Q^b$

Data source	Sample size	A	90% single response limit for a	95% mean response limit for a	b	R ²
All North American gravel-bed streams	94	3.68 (2.03)	2.03-6.68 (1.12-3.69)	3.45-3.94 (1.90-2.18)	0.5	0.80
All United Kingdom gravel-bed streams	86	2.99 (1.65)	1.86-4.79 (1.02-2.64)	2.83-3.16 (1.56-1.74)	0.5	0.80
<5% tree or shrub cover, or 'grass-lined' banks (UK streams)	36	3.70 (2.04)	2.64-5.20 (1.46-2.87)	3.49-3.92 (1.93-2.16)	0.5	0.92
≥5% tree or shrub cover (UK streams)	43	2.46 (1.36)	1.87-3.24 (1.03-1.79)	2.36-2.57 (1.30-1.42)	0.5	0.92

Note: R² refers to linear regression equations (not given) where b was variable. Exponent b was found not to be statistically different from 0.5, which was chosen for convenience.

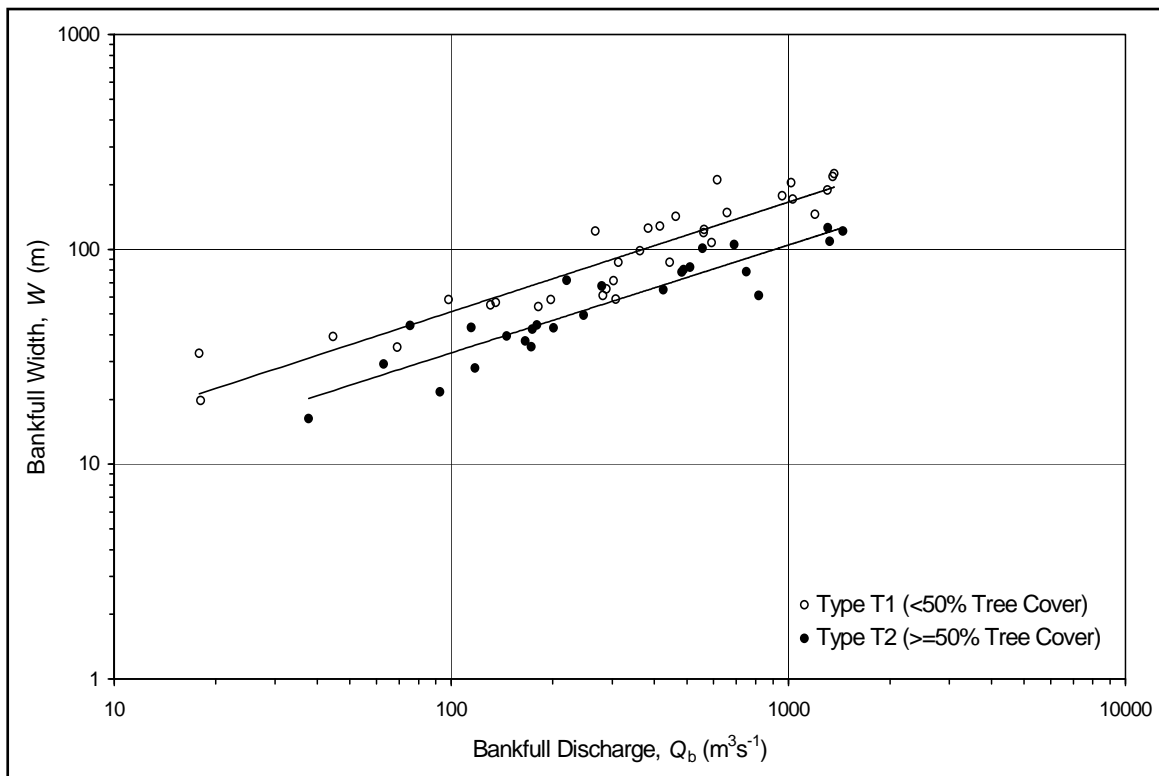


Figure 1. Best-fit hydraulic geometry relationships for width for U.S. sand-bed rivers with banks typed according to density of tree cover.

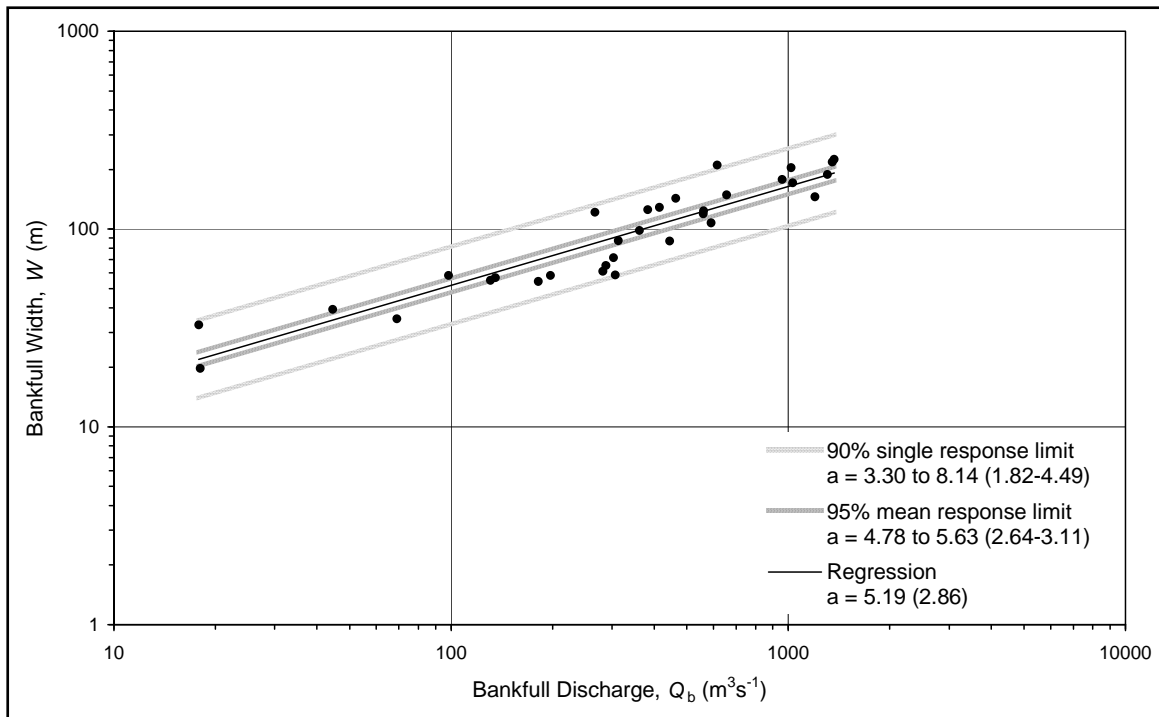


Figure 2. Confidence intervals applied to the hydraulic geometry equation for width based on 32 sand-bed streams with less than 50 percent tree cover on the banks (T1). S.I. Units – m and m³/sec (English Units ft and ft³/sec).

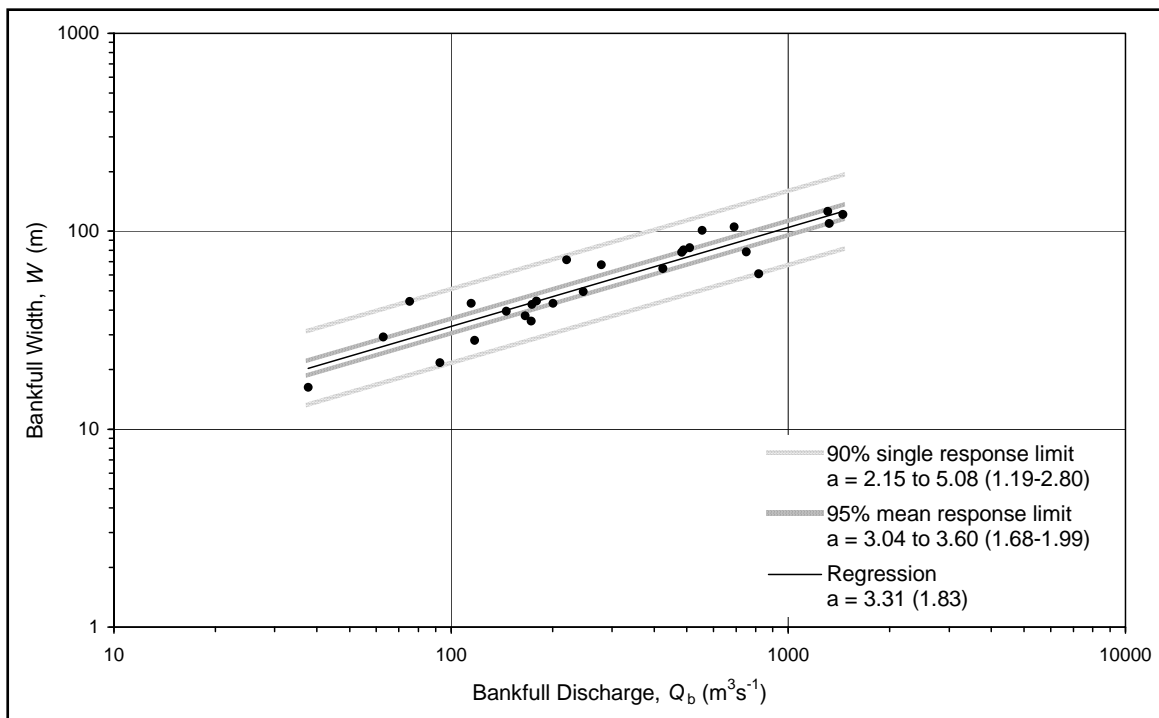


Figure 3. Confidence intervals applied to the width hydraulic geometry equation based on 26 sand-bed rivers with at least 50 percent tree cover on the banks (T2). S.I. Units – m and m³/sec (English Units ft and ft³/sec).

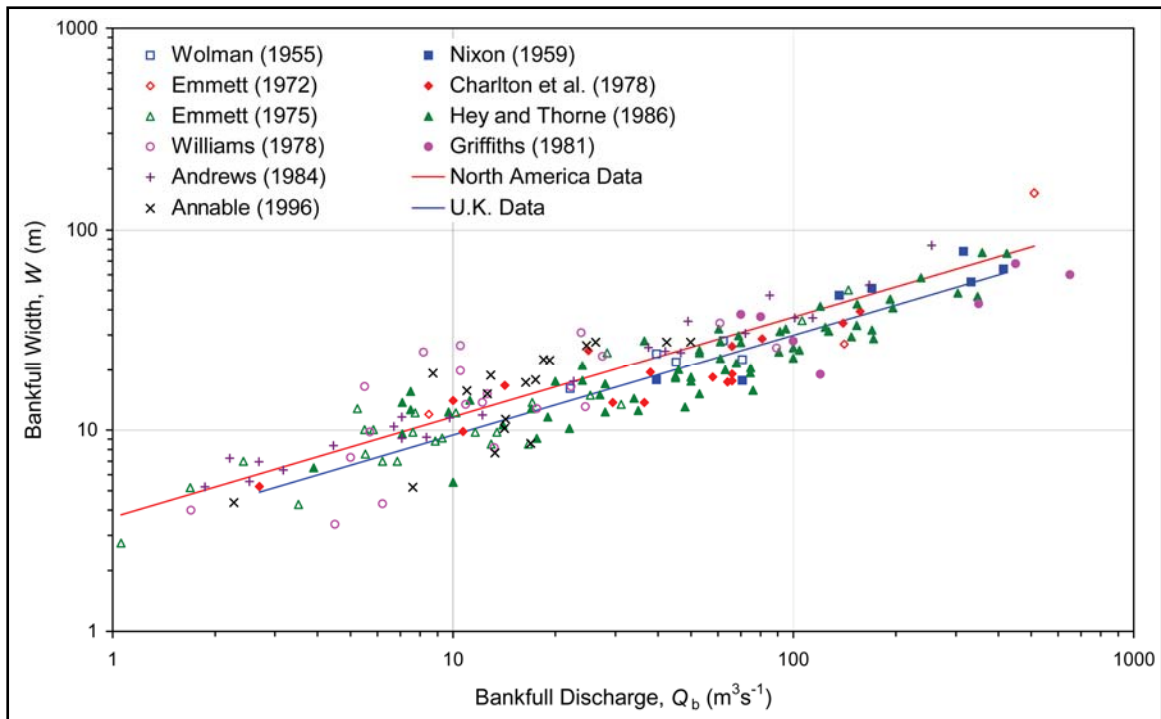


Figure 4. Downstream width hydraulic geometry for North American gravel-bed rivers, $W = 3.68Q_b^{0.5}$, and U.K. gravel-bed rivers, $W = 2.99Q_b^{0.5}$.

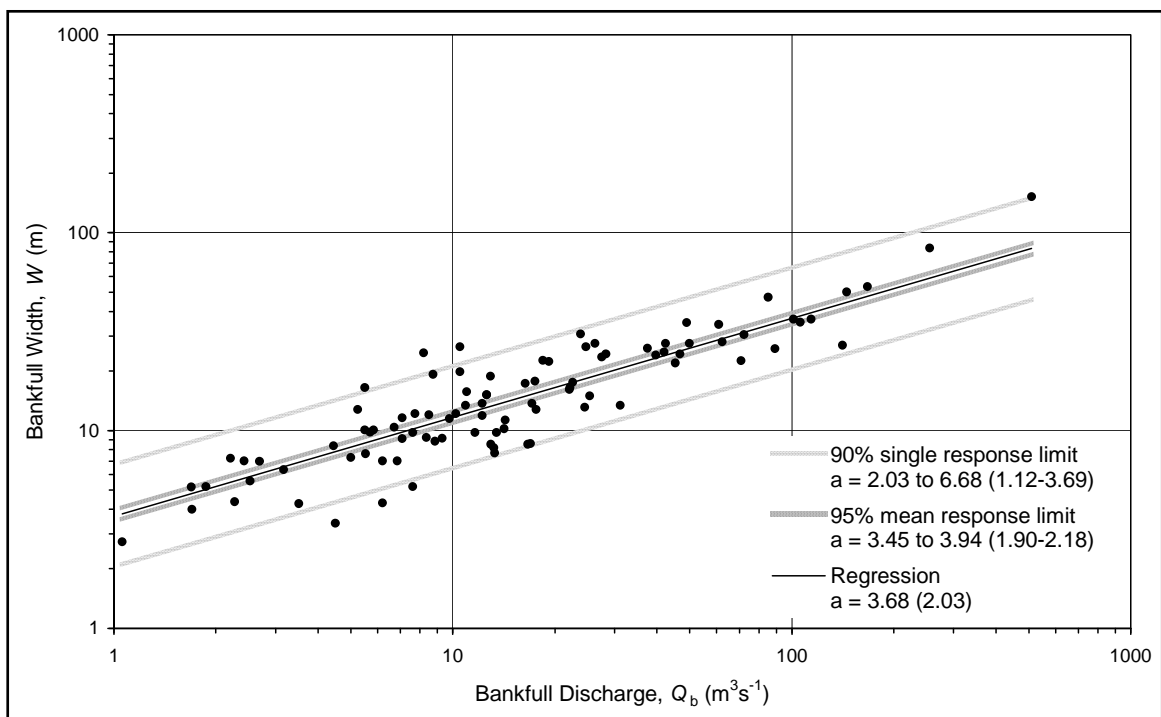


Figure 5. Downstream width hydraulic geometry for North American gravel-bed rivers, $W = a Q_b^{0.5}$ with confidence bands. Based on 94 sites in North America. S.I. Units – m and m³/sec (English Units ft and ft³/sec)

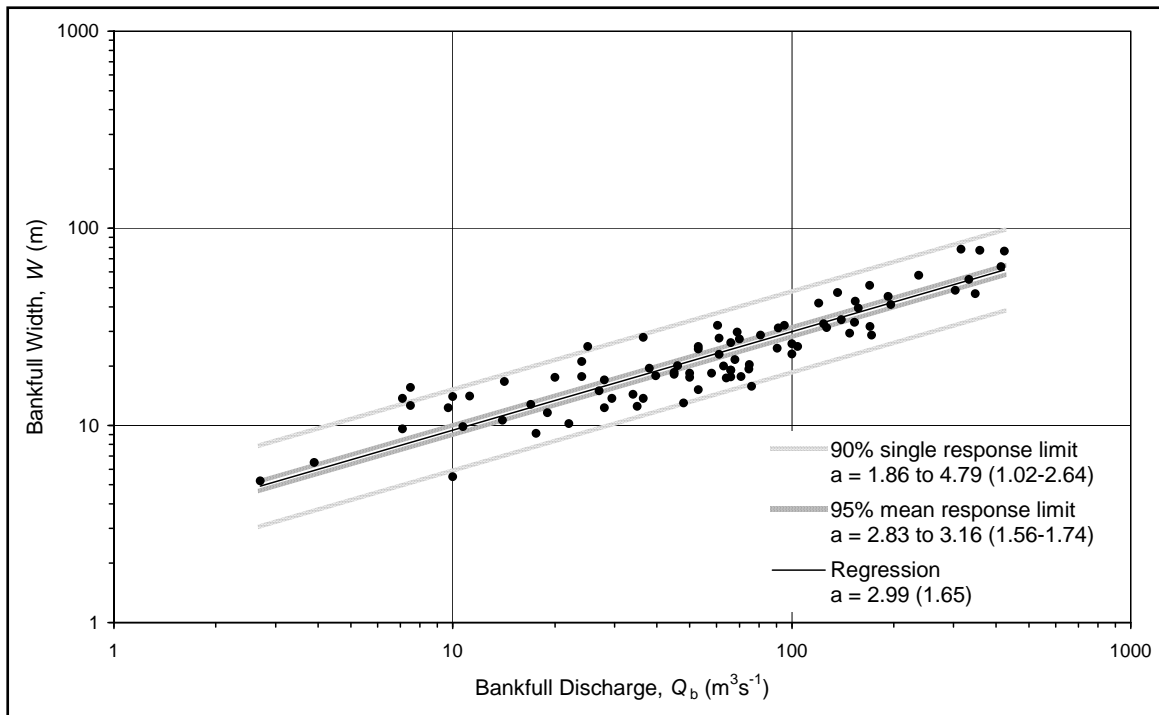


Figure 6. Downstream width hydraulic geometry for U.K. gravel-bed rivers, $W = a Q_b^{0.5}$ with confidence bands. Based on 86 sites in the U.K. S.I. units m and m^3/sec (English units ft and ft^3/sec).

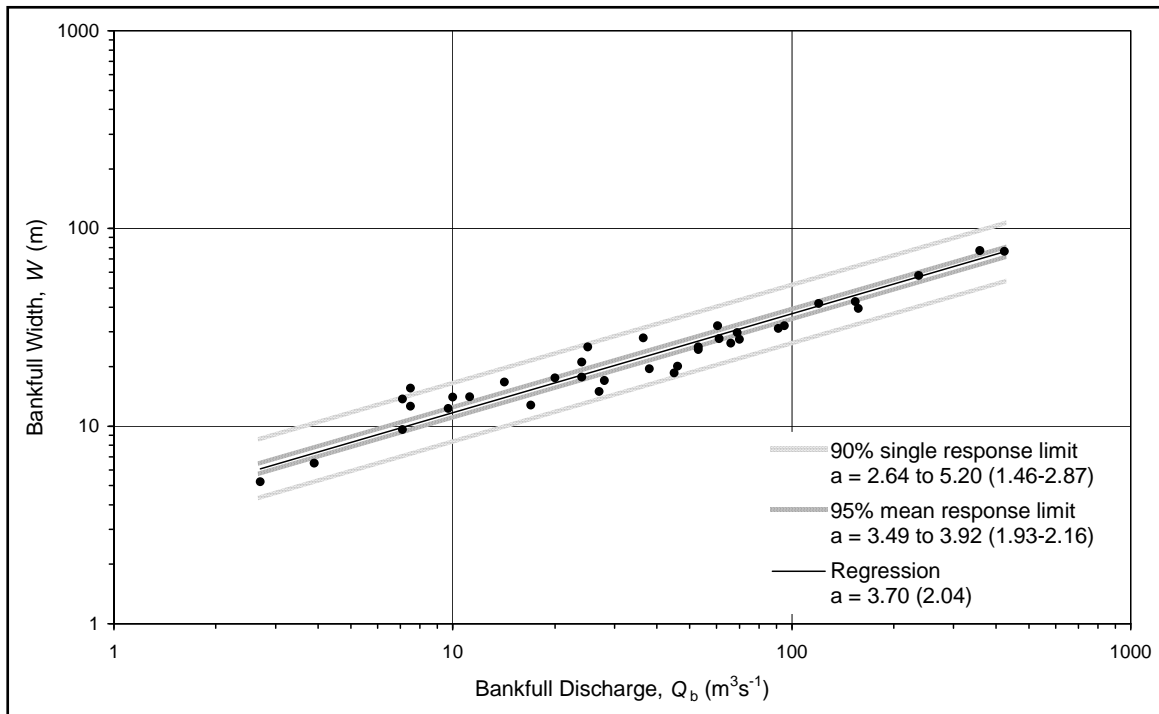


Figure 7. Downstream width hydraulic geometry for U.K. gravel-bed rivers, $W = a Q_b^{0.5}$ with confidence bands. Based on 36 sites in the U.K. with erodible banks, i.e., banks with a low density of trees. S.I. units m and m^3/sec (English units ft and ft^3/sec).

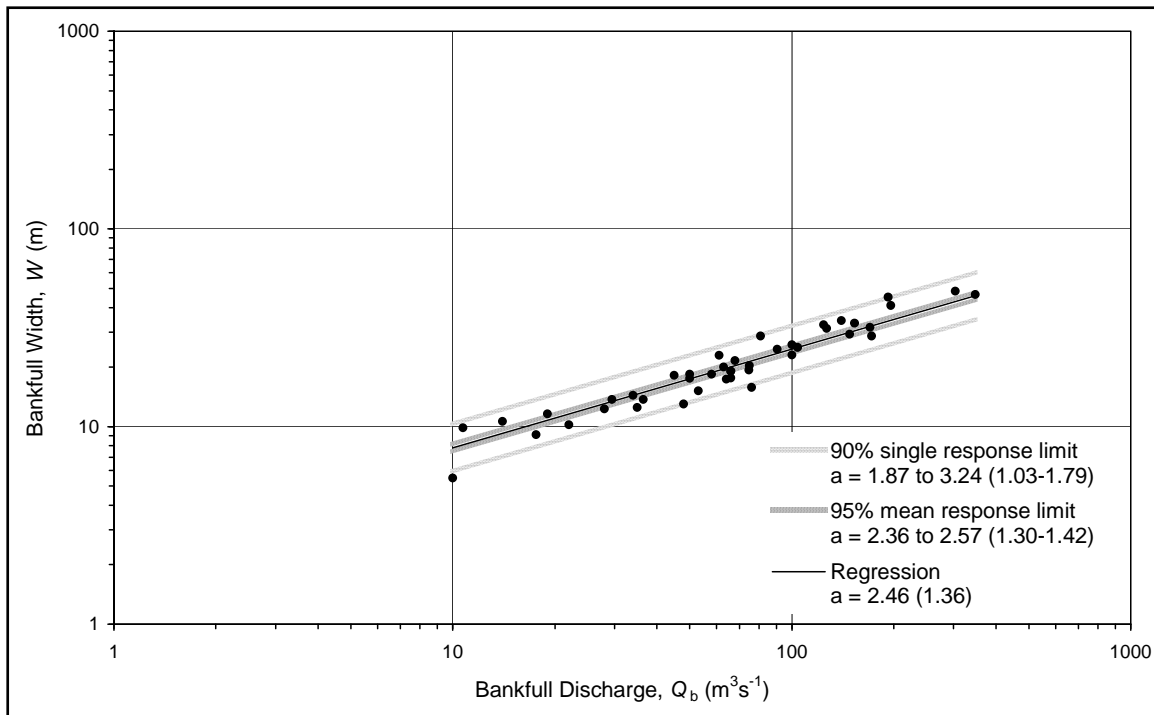


Figure 8. Downstream width hydraulic geometry for U.K. gravel-bed rivers, $W = a Q_b^{0.5}$ with confidence bands. Based on 43 sites in the U.K. with resistant banks, i.e., banks with a high density of trees. S.I. units m and m^3/sec (English units ft and ft^3/sec).

APPLICABILITY AND LIMITATIONS

Techniques described in this technical note are generally applicable to stream restoration projects that include revegetation of the riparian zone or bioengineering treatments.

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